DEVELOPMENT OF AIR-ENTRAINED, HIGH-STRENGTH CONCRETE: NORMAL WEIGHT CONCRETE

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of

CANADA CEMENT LAFARGE LIMITED

Work on this project was conducted under the auspices of the Canada Center for Mineral and Energy Technology, CANMET, Energy, Mines and Resources, Canada.

D.S.S. File No. : 23SQ.23440-4-9171

D.S.S. Contract Serial No. : OSQ84-00206

CANMET Scientific Authority: Mr. G.G. Carette

49 pp

AUGUST, 1987

MICROMEDIA

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ABSTRACT

The potential construction of offshore concrete platforms off the coast of Newfoundland has created a demand for high performance concrete made from local materials. This paper reports the development of air-entrained, high-strength concrete incorporating mineral admixtures and a high-range water reducer. In some of the mixtures, steel or polypropylene fibers were incorporated to improve the impact and abrasion resistance of concrete. Fourteen concrete mixtures comprising 45 batches were made in this investigation, and a total of 686 cylindrical, prism and slab specimens were tested.

It is concluded that air-entrained high-strength concrete with a strength > 80 MPa at 91 days can be produced using materials from the Atlantic provinces. The highest strength achieved was 85 MPa for a mixture incorporating 15% Class F fly ash, 6% condensed silica fume and a high-range water reducer. The concrete so developed has excellent frost resistance and very low permeability.

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FABRICATION DE BETON A AIR OCCLUS, A HAUTE RESISTANCE:

BETON DE DENSITE NORMALE

par

C. Bédard and K. Cail *

RESUME

La construction éventuelle de plates-formes pétrolières en béton, au large des côtes de Terre-Neuve, a créé une demande pour la mise au point de béton à rendement élevé à partir de matériaux locaux. Cette étude fait état de la production d'un béton à air occlus, à haute résistance, dont la composition inclus des adjuvants minéraux et des superplastifiants. Dans certains des mélanges , l'incorporation de fibres d'acier ou de polypropylène a permis une amélioration de la résistance du béton au choc et à l'abrasion. Au cours de cette étude, on a effectué quatorze mélanges de béton comprenant 45 gâchées et on a analysé un total de 686 éprouvettes cylindriques, prismatiques et en forme de dalles.

On en a conclu qu'il était possible de fabriquer du béton à air occlus, à haute résistance, ayant une résistance supérieure à >80 MPa, à 91 jours, en utilisant des matériaux des provinces canadiennes de l'Atlantique. La résistance la plus élevée mesurée a été de 85 MPa pour un mélange contenant 15% de cendres volantes de type F, 6% de fumée de silice et un superplastifiant. Un tel béton possède une excellente résistance au gel et une perméabilité extrêmement faible.

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INTRODUCTION

In recent years, CANMET has become increasingly involved in research for concrete for offshore structures. In addition to the in-house studies, a number of research projects are being performed by industry under the contracting-out policy of the department (1,2,3). Because of the need for high-performance concrete for offshore structures in the very severe environment of Eastern Canada, one of the research projects deals with the development of high-strength concretes using local cement and aggregates, together with chemical and mineral admixtures. Investigations dealing with lightweight high-strength concrete having a 28-day compressive strength > 60 MPa have been completed, and some of the results have been published (1). This paper reports the results of the first phase of an investigation dealing with the development of high-strength, normal weight concretes (> 70 MPa) using materials from the Canadian Atlantic provinces, with the added stipulation that the concretes, so developed, must be air-entrained, frost resistant and must have very low permeability.

This investigation is a part of CANMET's ongoing research project "Concrete for Offshore Structures". The next phase of this investigaton will involve the feasibility of producing the high-strength concrete at a commercial ready-mixed plant in St. John, New Brunswick.

SCOPE OF INVESTIGATION

The test program consisted of an evaluation of low permeability, high-strength normal weight concrete. The cement, fly ash and aggregates were obtained from the Atlantic provinces, while the condensed silica fume, fibers and chemical admixtures were obtained from other parts of the country. All mixtures incorporated a superplasticizer at water-to-cementing materials ratios of or below 0.27. The objective was to obtain the maximum strength achievable with the available materials. The following series of concrete mixtures were made:

Series I: Concrete Mixtures Without Fly Ash and Silica Fume

These concrete mixtures had a cement content of 500 kg/m^3 and were made with and without fibers.

Series II: Concrete Mixtures with Fly Ash

These mixtures were similar to those of Series I except that they incorporated fly ash as an addition to cement.

Series III: Concrete Mixtures with Silica Fume

These mixtures were similar to those of Series I except that they incorporated silica fume as an addition to cement.

Series IV: Concrete Mixtures with Fly Ash and Silica Fume

These mixtures were similar to those in Series I except that they incorporated both fly ash and silica fume as additions to cement.

A total of 14 concrete mixtures involving 45 batches were made and a total of 686 concrete cylinder, prism and slab specimens were made to fulfill the test program requirements.

MATERIALS USED

Cement

ASTM Type I (CSA Type 10) Portland cement was used. The chemical analysis and physical properties are given in Table 1.

Fly Ash

An ASTM Class F fly ash was used. The chemical analysis and physical properties are shown in Table 1.

Condensed Silica Fume

A condensed silica fume was used. The chemical analysis and physical properties are shown in Table 1.

Aggregates

Crushed gravel of 14-mm maximum size was used as the coarse aggregate and natural sand was used as the fine aggregate. The relative densities of the coarse and fine aggregates were 2.67 and 2.61, respectively, and the corresponding absorption values were 1.3 and 1.4. The sand fineness modulus was 2.69.

Fibers

Polypropylene and steel fibers were used. The physical properties of the fibers are shown in Table 2.

Air-Entraining Admixture

The air-entraining admixture used in the concrete mixtures was a sulphonated hydrocarbon type.

High-Range Water Reducer (Superplasticizer)

A sulphonated naphtalene formaldehyde condensate type superplasticizer was used in the concrete mixtures. It was a 42% aqueous solution with a density of 1.20.

CONCRETE MIXTURES

A total of 14 concrete mixtures involving 45 batches were made in this investigation and the details of the mixture program is shown in Table 3. The Type I Portland cement was kept constant at 500 kg/m^3, as was the water-to-cement ratio at 0.27. The fly ash and condensed silica fume were used as replacement for the fine aggregate. The loss of workability due to the use of silica fume and fibers was compensated for by the use of a superplasticizer.

All but three mixtures were prepared in triplicate batches to obtain sufficient concrete specimens for the program requirements. A fourth batch was prepared for mixtures R1, R4 and S4 to make the required specimens for permeability and creep testing. Mixing was carried out in a laboratory drum mixer with the supplementary cementing materials added to the mixer simultaneously with the cement. Total mixing time was 6 minutes for the non-fiber-reinforced concrete mixtures and 8 minutes for the fiber-reinforced concrete mixtures.

In each of the three series of concrete mixtures, both fly ash and silica fume were introduced as an addition to the Portland cement, fly ash at 15%, and silica fume at 6% of the cement content.

Steel fibers were added to the "S" series of mixtures at a rate of 50 kg/m^3 and polypropylene fibers were added to the "P" series of mixtures at a rate of 1 kg/m^3. The fibers were introduced into the concrete at the end of the mixing cycle and continued mixing for an additional two minutes.

The concrete mix proportions and the properties of fresh concrete, that is slump, air content, and density were determined and are given in Tables 4 to 7. The workability of the fiber-reinforced concrete was determined by the inverted slump cone test and the test results are given in Tables 4 to 7.

CASTING AND CURING OF THE TEST SPECIMENS

Twenty 100 x 200-mm cylinders, nine 150 x 300-mm cylinders, two 75 x 75 x 300-mm prisms, eight 75 x 75 x 350-mm prisms and two 300 x 300 x 75-mm slabs were cast for each mixture. An additional eight 150 x 300-mm cylinders were cast from mixtures R1, R4 and S4 for additional testing. The details of test specimens cast are shown in Table 8.

Test specimens were cast in two layers and compacted by means of a vibrating table. After casting, the moulded specimens were covered with water-saturated burlap and left in the casting room at 23± 1.7°C for 24 h. They were then demoulded and transferred to the standard moist curing room until required for testing.

TESTING OF SPECIMENS

The testing schedule is shown in Table 8. The test cylinders for compressive strength and for modulus of elasticity were capped with a sulphur capping compound on both ends and tested in accordance with ASTM C 39 for compressive strength up to 365 days and C 469 for modulus of elasticity at 28 and 365 days. Test prisms were used to determine the flexural strength at 28 and 365 days.

To determine the impact strength of concrete according to ACI 544.2R.78, the top 75-mm of three cylinders was cut off from 150 x 300-mm concrete cylinders.

The 300 x 300-mm test slabs were used to determine the Abrasion Resistance of concrete surface by the Ball Bearing Procedure of ASTM C 779 at 91 and 365 days.

The two cylinders for the microscopical determination of Air-Void content in hardened concrete were tested according to ASTM C 457.

The test prisms for drying shrinkage were subjected to air drying after an initial moist curing period of 28 days. Shrinkage strains have been monitored at 23± 1.7°C and 50± 4% of relative humidity for a period of 64 weeks.

Freezing and thawing tests were performed on two prisms per mixture using Procedure A of ASTM C 666, with the specimens being subjected to a total of 300 repeated cycles of freezing in water and thawing in water.

Permeability measurements on three separate mixtures were performed by using a test procedure developed at CANMET.

The creep strains were determined according to ASTM C 512 for a period of 365 days. A constant applied stress of 40% of the compressive strength of the concrete at the age of loading was applied.

TEST RESULTS

The compressive strength test results along with the flexural strength test results and modulus of elasticity data for the 14 mixtures are given in Table 9. The initial impact strength and abrasion depth data are given in Table 10. The air content of fresh concrete and the air-void parameters of hardened concrete plus the freeze-thaw test results are summarized in Table 11. Values for length change (shrinkage) and water permeability are given in Table 12.

DISCUSSION

Properties of Fresh Concrete

All mixtures were very stiff and "gluey" to work with, but under vibration and rodding, the cohesive forces were reduced and the mixtures became quite workable. In order to achieve a satisfactory workability and reasonable response to vibration, slumps should be greater than 80-mm for all the mixtures investigated. The workability of the mixtures incorporating fiber were similar to the workability of the reference mixtures.

Because of the dry nature of the mixture, there was some problem getting proper dispersion of polypropylene fiber nets, but no such problems were encountered with steel fibers.

No difficulty was experienced in entraining up to 4.0% air in the concrete mixtures investigated. The densities averaged 2380 kg/m^3 for all mixtures except those containing steel fibers, for which the densities were slightly higher at 2420 kg/m^3.

Compressive Strength

The average strength of the test specimens cast from all of the concrete mixtures at 91 days and one year was 79.5 MPa and 87.7 MPa, respectively. The two non-air-entrained mixtures gave higher strength at virtually all ages (Table 9).

Although the compressive strengths for the 14 mixtures investigated cover a wide range, in general, those mixtures containing silica fume and fly ash or silica fume only, gave higher early strengths as compared with the reference mixes and the mixtures containing fly ash only. An increase of approximately 10% is achieved at 7 days for mixtures incorporating silica fume and fly ash or silica fume only. As for later age strength, the mixtures containing fly ash only or fly ash and silica fume gave higher results at 91 days and 1 year.

As expected, the addition of fibers to the concrete had little effect on compressive strength.

Flexural Strength

In most cases, the flexural strength results follow the same pattern as those for the compressive strength. In general, there was a 10% increase in flexural strength between 28 days and 1 year.

The test specimens cast from concrete containing polypropylene and steel fibers gave higher strengths than the reference mixtures, which was due to the tensile reinforcing properties of the fibers. The flexural strength of the

concrete incorporating fibres was however more variable than the flexural strength of the reference concrete.

The highest flexural strengths achieved at 1 year were with concretes containing steel fibers and were of the order of 13.5 MPa.

Modulus of Elasticity

The 28 day and 1 year Young's modulus of elasticity values for the 14 mixtures investigated ranged from 31.2 to 35.3 GPa and 33.3 to 37.9 GPa, respectively (Table 9).

Impact Strength

The initial impact data for test specimens cast from the fourteen mixtures are given in Table 10. The wide scatter of the data makes it difficult to correlate the results and, more importantly, it indicates that the test procedure itself does not produce reliable data.

The impact strength test is done manually and is labour intensive. If the test is continued to be used, equipment which automatically lifts the drop weight and counts the number of blows should be developed.

Abrasion Resistance

The abrasion resistance of the concrete specimens was determined by the Ball Bearing Procedure of ASTM C 779. The values of abrasion depth varied from a high of 0.0260" to a low of 0.0033" (Table 10). The average value of depth for concrete specimens containing steel fiber mixtures was 0.0078" and 0.0165" for the concrete specimens containing polypropylene. This is considerably better than the average of 0.0204" for the reference mixtures without fibers.

Microscopical Determination of Air-Void Content

For air-entrained concrete, the spacing factors and specific surface range from 0.131 to 0.323-mm and 10.6 to 26.9 mm^2/mm^3, respectively. Only two of the test specimens for the concrete mixtures investigated meet the criteria of specific surface greater than 25 mm^2/mm^3 and spacing factor (L) less than 0.200-mm, which are the generally accepted criteria agreed upon to ensure a frost resistant concrete (4,5,6).

Despite the above results, the performance of the concrete specimens under freezing-thawing cycling was excellent. In all cases, this is probably due to the high-strength and low permeability of the concretes investigated. The durability factors for the concretes investigated ranged from 99 to 101% after 300 cycles (Table 11).

The measurement of the air-voids in the hardened concrete was consistently greater than the value of entrained air content in the fresh concrete as determined by the pressure meter (Table 11). The average difference between the two values was 1.4% (average of results of all test series).

Drying Shrinkage

The drying shrinkage of the test prisms was determined over a period of 64 weeks, with the first readings being taken at 4 days after an initial moist curing period of 28 days. All specimens were air dried at 50% relative humidity and at 23°C± 1.7°C. The test values (Table 12) indicate that the drying shrinkage is little affected by the addition of either fly ash, silica fume or fibers. The average shrinkage of test prisms at 32 weeks is 0.055% (average of results of all test series).

Permeability

The permeability test was performed according to a procedure developed at CANMET (7).

By this method, after 8 months, there was no flow through the specimens, regardless of the composition of concrete. In order to determine the depth of penetration of water, one of the specimens was split open. An examination of the concrete surface revealed that the water had penetrated a distance of only about 12.5 mm. Based upon the other available data on higher water-to-cement ratio concretes, it is estimated that the concrete under test had a coefficient of permeability of well below 10^{-13} m/s. It appears that in very low water-to-cement ratio concrete, the determiation of the depth of penetration of water may be a more appropriate parameter rather than the coefficient of permeability.

Creep

Creep tests according to ASTM C-512 were carried out on series R4 and S4 to determine the load-induced time dependent strain at one year.

The R4 series gave a creep value of 600 micro strains, while the S4 series gave 1000 micro strains.

CONCLUSIONS

1. Air-entrained concretes having very high compressive strengths can be produced using conventional cement and aggregates from the Atlantic provinces. However, the incorporation of silica fume and high-range water reducers becomes necessary to achieve these strengths at early ages. Compressive strength of 80 MPa at 91 days was achieved for concrete incorporating 15% Class F fly ash, 6% condensed silica fume and a high-range water reducer.

2. The values of the bubble spacing factor L and specific surface, in general, did not comply with the generally established limits of 0.20-mm and 25 mm^2/mm^3. In spite of this, the concrete specimens performed excellently in the freezing and thawing test (ASTM C 666 Procedure A). Consideration should therefore be given to reviewing the above limits of air-void parameters for high-strength concrete.

3. The incorporation of fibers in concrete generally improved the flexural strength and abrasion resistance of concrete. This was particularly so for concrete containing steel fibers. The 28-day flexural strength of concrete containing steel fibers was, on the average, 13% higher than the corresponding strength of concrete incorporating polypropylene fibers, which in turn, was 8% higher than the strength of reference concrete without fibers.

4. The drop hammer impact test used in this study has poor reproducibility with an average within-batch coefficient of variation of 68%.

ACKNOWLEDGEMENTS

The laboratory investigations were performed at the Research and Technical Centre, Canada Cement Lafarge Ltd., Montréal, under a DSS contract 23SQ.23440-4-9171. CANMET Scientific Authority for the project was G.G. Carette and principal researchers at Canada Cement Lafarge were Claude Bédard and Kevin Cail. The investigation was performed in accordance with the work statement prepared by the Scientific Authority.

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Table 1. Chemical Analysis and Physical Properties of Portland Cement and Supplementary Cementing Materials

Description of Test	ASTM Type I Cement	Fly Ash	Silica Fume
Chemical Analysis, %			
SiO_2	20.2	44.93	95.41
Al_2O_3	5.9	25.79	1.09
Fe_2O_3	2.2	19.06	0.00
CaO	62.8	0.92	0.32
MgO	1.4	1.43	0.73
Na_2O	0.10	0.82	-
K_2O	1.26	0.54	0.61
SO_3	4.0	3.16	0.24
Mn_2O_3	-	0.67	-
Loss on Ignition	2.1	2.88	1.80
Total	100.0	100.2	99.20
$SiO_2 + Al_2O_3 + Fe_2O_3$	-	89.8	-
Potential Compound Composition, %			
C_4AF	6.7		
C_3A	11.9		
C_3S	48.0		
C_2S	21.7		
$C_3S + C_2S$	69.7		
Physical Tests - General			
Time of Set (Vicat Needle), min., Initial	115		
Final	220		
Fineness: -45 μm	81.7		
Blaine Surface Area, m^2/kg	376		
% Retained on 45 um by wet sieving		14.5	
Fineness			19,000 m^2/kg
Water Requirement, %		97	139
Pozzolanic Activity Index with:			
Portland Cement at 28-d,		94	119.1
% Lime, MPa		6.7	12.5
Physical Tests - Mortar Compressive Strength, MPa			
3-d	28.0		
7-d	32.2		
28-d	37.3		

Table 2. Physical Properties - Fibers

FIBER	PHYSICAL CHARACTERISTICS
Polypropylene	Length : 52 mm Specific Gravity: 0.9
Steel	Length : 50 mm Diameter : 0.5 mm Specific Gravity: 7.85 Length/Diameter : 100

Table 3. Details of Concrete Mixtures

ASTM Type I Portland Cement, kg/m^3	500													
Condensed Silica Fume, kg/m^3	0						30							
Percent of Cement Content	0%						6%							
Fly Ash, kg/m^3	0			75			0			75				
Percent of Cement Content	0			15%			0			15%				
Total Cementing Material, kg/m^3	500			575			530			605				
Mixture Code*	R1	S1	P1	R2	S2	P2	R3	S3	P3	R4	NR4	S4	P4	NS4
Air-Entrained (4.5% ± 1%)	x	x	x	x	x	x	x	x	x	x	-	x	x	-
Steel Fiber-Reinforced	-	x	-	-	x	-	-	x	-	-	-	x	-	x
Polypropylene Fiber-Reinforced	-	-	x	-	-	x	-	-	x	-	-	-	x	-

* R = Reference Mixtures
S = Steel Fiber Mixtures
P = Polypropylene Fiber Mixtures
N = Non-Air-Entrained Mixtures

Table 4. Series I: Mixture Proportions and Properties of Fresh Concrete Without Fly Ash or Condensed Silica Fume

		Mixture Proportions for 1 m^3											Properties of Fresh Concrete				
Mixture Code	Batch No.	Water-to-Cement Ratio	Water-to-Cementing Materials Ratio	Cement kg	Fly Ash kg	Silica Fume kg	Fine Aggregate kg	Coarse Aggregate kg	Steel Fibers kg	Polypropylene Fibers kg	Water kg	Superplasticizer % by Weight of Cement	Slump mm	Air %	Density kg/m^3	Inv. Slump Cone Test, seconds	
																Initial	Final
R1	1	0.27	0.27	510	--	--	710	1060	--	--	137	1.90	100	3.9	2425	--	--
	2	0.27	0.27	509	--	--	705	1060	--	--	137	1.66	95	(3.4)	2420	--	--
	3	0.27	0.27	504	--	--	700	1045	--	--	136	1.90	140	3.8	2395	--	--
S1	1	0.27	0.27	506	--	--	760	960	50	--	136	2.64	200	4.0	2425	42	--
	2	0.27	0.27	506	--	--	760	960	50	--	136	2.64	190	4.4	2425	--	--
	3	0.27	0.27	508	--	--	760	965	50	--	137	2.64	180	4.0	2435	--	57
P1	1	0.27	0.27	503	--	--	695	1045	--	1	136	1.67	160	3.8	2390	19	--
	2	0.27	0.27	506	--	--	700	1050	--	1	136	1.43	80	3.8	2405	--	--
	3	0.27	0.27	507	--	--	705	1055	--	1	137	1.54	105	3.7	2410	--	29

Table 5. Series II: Mixture Proportions and Properties of Fresh Concrete Incorporating Fly Ash

Mixture Code	Batch No.	Mixture Proportions for 1 m^3											Properties of Fresh Concrete				
		Water-to-Cement Ratio	Water-to-Cementing Materials Ratio	Cement kg	Fly Ash kg	Silica Fume kg	Fine Aggregate kg	Coarse Aggregate kg	Steel Fibers kg	Polypropylene Fibers kg	Water kg	Superplasticizer % by Weight of Cement	Slump mm	Air %	Density kg/m^3	Inv. Slump Cone Test, seconds	
																Initial	Final
R2	1	0.27	0.23	504	76	--	620	1050	--	--	136	2.13	100	3.4	2400	--	--
	2	0.27	0.24	506	76	--	620	1050	--	--	137	1.88	115	3.9	2390	--	--
	3	0.27	0.24	506	76	--	620	1055	--	--	137	2.16	110	3.8	2405	--	--
S2	1	0.27	0.23	500	75	--	685	980	50	--	135	2.68	135	4.1	2440	30	--
	2	0.27	0.23	499	75	--	685	975	50	--	135	2.68	120	3.9	2435	--	--
	3	0.27	0.23	500	75	--	685	980	50	--	135	2.69	130	3.8	2440	--	45
P2	1	0.27	0.23	503	76	--	620	1045	--	1	136	2.04	100	3.8	2395	17	--
	2	0.27	0.23	504	76	--	620	1050	--	1	136	2.02	100	4.0	2400	--	--
	3	0.27	0.23	505	76	--	620	1050	--	1	137	2.02	115	3.9	2405	--	24

Table 6. Series III: Mixture Proportions and Properties of Fresh Concrete Incorporating Condensed Silica Fume

Mixture Code	Batch No.	Mixture Proportions for 1 m^3											Properties of Fresh Concrete				
		Water-to-Cement Ratio	Water-to-Cementing Materials Ratio	Cement kg	Fly Ash kg	Silica Fume kg	Fine Aggregate kg	Coarse Aggregate kg	Steel Fibers kg	Polypropylene Fibers kg	Water kg	Superplasticizer % by Weight of Cement	Slump mm	Air %	Density kg/m^3	Inv. Slump Cone Test, seconds	
																Initial	Final
R3	1	0.27	0.26	499	--	29	660	1040	--	--	135	1.58	90	4.5/3.5	2370/2390	--	--
	2	0.27	0.26	500	--	30	660	1040	--	--	135	1.58	80	4.6/3.9	2375/2390	--	--
	3	0.27	0.26	502	--	30	665	1045	--	--	136	1.69	105	5.4/4.2	2350/2385	--	--
S3	1	0.27	0.26	507	--	30	690	980	51	--	137	2.16	170	7.0/4.8	2405	40	--
	2	0.27	0.26	506	--	30	690	975	50	--	137	2.16	145	5.5/3.8	2400	--	--
	3	0.27	0.26	506	--	30	690	980	50	--	137	2.16	175	7.4/3.3	2400	--	54
P3	1	0.27	0.26	501	--	30	660	1045	--	1	136	1.68	105	4.4	2385	18	--
	2	0.27	0.26	503	--	30	665	1045	--	1	136	1.69	85	4.4	2390	--	--
	3	0.27	0.26	502	--	30	665	1045	--	1	136	1.68	90	4.3	2385	--	45

Table 7. Series IV: Mixture Proportions and Properties of Fresh Concrete Incorporating Fly Ash and Condensed Silica Fume

		Mixture Proportions for 1 m^3											Properties of Fresh Concrete				
Mixture Code	Batch No.	Water-to-Cement Ratio	Water-to-Cementing Materials Ratio	Cement kg	Fly Ash kg	Silica Fume kg	Fine Aggregate kg	Coarse Aggregate kg	Steel Fibers kg	Polypropylene Fibers kg	Water kg	Superplasticizer % by Weight of Cement	Slump mm	Air %	Density kg/m^3	Inv. Slump Cone Test, seconds	
																Initial	Final
R4	1	0.27	0.22	495	75	30	565	1040	--	--	134	2.10	170	5.4	2350	--	--
	2	0.27	0.22	500	75	30	570	1050	--	--	135	1.74	125	4.6	2370	--	--
	3	0.27	0.22	500	75	30	570	1050	--	--	135	1.74	125	4.7	2370	--	--
NR4*	1	0.27	0.22	502	76	30	625	1055	--	--	136	2.20	145	1.8	2435	--	--
	2	0.27	0.22	505	76	31	625	1060	--	--	136	2.04	130	2.1	2445	--	--
	3	0.27	0.22	504	76	30	625	1055	--	--	136	1.95	120	2.2	2440	--	--
S4	1	0.27	0.23	501	75	30	625	980	50	--	136	2.04	110	4.4	2410	38	--
	2	0.27	0.23	506	76	30	635	990	50	--	137	2.03		4.0		--	--
	3	0.27	0.23	506	76	30	635	990	50	--	137	2.06	110	4.2	2435	--	43
P4	1	0.27	0.22	502	76	30	575	1055	--	1	136	1.75	130	4.0	2385	15	--
	2	0.27	0.22	496	75	30	565	1040	--	1	134	1.75	130	5.0	2355	--	--
	3	0.27	0.22	497	75	30	565	1045	--	1	134	1.75	140	4.6	2360	--	11
NS4*	1	0.27	0.22	506	76	30	685	990	50	--	137	2.21	140	2.4	2485	99	--
	2	0.27	0.22	507	76	30	685	990	51	--	137	2.21	145	2.2	2490	--	--
	3	0.27	0.22	504	75	30	685	985	50	--	136	2.67	135	2.3	2475	--	76

* Entrapped air only; no air entraining admixture was used.

Table 8. Testing Schedule for Hardened Concrete

TEST	AGE	BATCH			
		1	2	3	4
		NO. OF SPECIMENS TESTED			
1) Compressive Strength (ASTM C 39) of 100 x 200-mm cylinders	1-d	2		1	
	7-d	2		1	
	28-d	2		1	
	91-d	2		1	
	1-y	2		1	
	2-y	2		1	
2) Flexural Strength (ASTM C 78) of 75 x 75 x 350-mm prisms	28-d			2	
	1-y			2	
	2-y			2	
3) Modulus of Elasticity (ASTM C 469) of 150 x 300-mm cylinders	28-d		2		
	1-y		2		
	2-y		2		
4) Impact Strength (ACI 544.2R.78) of 150 x 65-mm samples cut off from 150 x 300-mm cylinders	28-d	2	1		
5) Abrasion Resistance of Concrete by the Ball Bearing Procedure of ASTM C 779, as measured on 300 x 300 x 75-mm slabs	91-d		3		
	1-y		3		
6) Microscopical Determination of Air-Void Content in Hardened Concrete (ASTM C 457), 100 x 200-mm cylinders				2	
7) Length Change of Hardened Concrete (Shrinkage) in Air Storage (ASTM C 157), as measured on 75 x 75 x 300-mm prisms				2	
8) Resistance of Concrete to Rapid Freezing and Thawing (ASTM C 666, Proc. A), as measured on 75 x 75 x 300-mm prisms				2	
9) Water Permeability of Hardened Concrete, as measured on 150 x 300-mm cylinders for 3 mixture series: R1, R4, and S4	28-d				2
10) Creep of Concrete in Compression (ASTM C 512), as measured on 150 x 300-mm cylinders for 2 mixture series: R4 and S4					6

Table 9. Strength Properties and Young's Modulus of Concrete

Mixture Code	Water-to-Cementing Materials Ratio	Cementing Content, kg/m^3	Compressive Strength, MPa					Flexural Strength, MPa		Modulus of Elasticity, GPa	
			1-d	7-d	28-d	91-d	1-y	28-d	1-y	28-d	1-y
R1	0.27	508	35.1	59.2	66.2	75.4	84.5	7.3	8.3	32.8	35.5
R2	0.24	581	33.3	58.2	66.0	77.3	91.0	7.7	8.9	31.2	34.9
R3	0.26	531	43.0	63.7	75.5	78.0	83.9	8.7	8.9	33.1	34.1
R4	0.22	605	39.9	59.7	74.2	80.7	84.2	8.3	9.1	32.0	33.3
NR4	0.22	610	45.5	68.9	81.4	85.1	93.4	10.0	10.2	35.3	35.9
P1	0.27	505	37.8	56.7	63.6	74.3	82.2	7.8	8.6	32.5	34.9
P2	0.23	580	39.0	57.8	66.7	77.4	88.4	8.6	9.5	32.5	36.1
P3	0.26	532	40.5	61.6	72.4	77.1	85.7	9.5	7.9*	33.5	36.3
P4	0.22	603	43.5	64.7	72.7	74.5	84.3	8.8	10.0	31.8	34.0
S1	0.27	506	31.5	59.5	66.4	74.6	81.7	7.9	13.5	32.5	35.6
S2	0.23	575	35.7	60.6	69.2	81.3	90.7	10.3	10.0	31.4	35.6
S3	0.26	536	45.3	67.8	78.5	83.6	90.5	9.9	11.6	33.5	35.7
S4	0.23	610	50.3	66.6	85.2	85.9	92.8	11.1	13.4	33.8	37.0
NS4	0.22	612	49.2	70.0	80.5	88.4	95.4	10.8	10.6	35.3	37.9

Table 8. Testing Schedule for Hardened Concrete

TEST	AGE	BATCH			
		1	2	3	4
		NO. OF SPECIMENS TESTED			
1) Compressive Strength (ASTM C 39) of 100 x 200-mm cylinders	1-d	2		1	
	7-d	2		1	
	28-d	2		1	
	91-d	2		1	
	1-y	2		1	
	2-y	2		1	
2) Flexural Strength (ASTM C 78) of 75 x 75 x 350-mm prisms	28-d			2	
	1-y			2	
	2-y			2	
3) Modulus of Elasticity (ASTM C 469) of 150 x 300-mm cylinders	28-d		2		
	1-y		2		
	2-y		2		
4) Impact Strength (ACI 544.2R.78) of 150 x 65-mm samples cut off from 150 x 300-mm cylinders	28-d	2	1		
5) Abrasion Resistance of Concrete by the Ball Bearing Procedure of ASTM C 779, as measured on 300 x 300 x 75-mm slabs	91-d		3		
	1-y		3		
6) Microscopical Determination of Air-Void Content in Hardened Concrete (ASTM C 457), 100 x 200-mm cylinders				2	
7) Length Change of Hardened Concrete (Shrinkage) in Air Storage (ASTM C 157), as measured on 75 x 75 x 300-mm prisms				2	
8) Resistance of Concrete to Rapid Freezing and Thawing (ASTM C 666, Proc. A), as measured on 75 x 75 x 300-mm prisms				2	
9) Water Permeability of Hardened Concrete, as measured on 150 x 300-mm cylinders for 3 mixture series: R1, R4, and S4	28-d				2
10) Creep of Concrete in Compression (ASTM C 512), as measured on 150 x 300-mm cylinders for 2 mixture series: R4 and S4					6

Table 9. Strength Properties and Young's Modulus of Concrete

Mixture Code	Water-to-Cementing Materials Ratio	Cementing Content, kg/m^3	Compressive Strength, MPa					Flexural Strength, MPa		Modulus of Elasticity, GPa	
			1-d	7-d	28-d	91-d	1-y	28-d	1-y	28-d	1-y
R1	0.27	508	35.1	59.2	66.2	75.4	84.5	7.3	8.3	32.8	35.5
R2	0.24	581	33.3	58.2	66.0	77.3	91.0	7.7	8.9	31.2	34.9
R3	0.26	531	43.0	63.7	75.5	78.0	83.9	8.7	8.9	33.1	34.1
R4	0.22	605	39.9	59.7	74.2	80.7	84.2	8.3	9.1	32.0	33.3
NR4	0.22	610	45.5	68.9	81.4	85.1	93.4	10.0	10.2	35.3	35.9
P1	0.27	505	37.8	56.7	63.6	74.3	82.2	7.8	8.6	32.5	34.9
P2	0.23	580	39.0	57.8	66.7	77.4	88.4	8.6	9.5	32.5	36.1
P3	0.26	532	40.5	61.6	72.4	77.1	85.7	9.5	7.9*	33.5	36.3
P4	0.22	603	43.5	64.7	72.7	74.5	84.3	8.8	10.0	31.8	34.0
S1	0.27	506	31.5	59.5	66.4	74.6	81.7	7.9	13.5	32.5	35.6
S2	0.23	575	35.7	60.6	69.2	81.3	90.7	10.3	10.0	31.4	35.6
S3	0.26	536	45.3	67.8	78.5	83.6	90.5	9.9	11.6	33.5	35.7
S4	0.23	610	50.3	66.6	85.2	85.9	92.8	11.1	13.4	33.8	37.0
NS4	0.22	612	49.2	70.0	80.5	88.4	95.4	10.8	10.6	35.3	37.9

Table 10. Impact and Abrasion Resistance of Concrete

Mixture Code	Water-to-Cementing Materials Ratio	Cementing Content, kg/m^3	Initial Impact Strength, # of Blows			Abrasion Depth, Inches
			Top	Within Batch Variation		
				S.D.	C.V.	
R1	0.27	508	59	47.3	80.1	0.0221
R2	0.24	581	298	476.3	159.8	0.0134
R3	0.26	531	358	199.8	55.8	0.0201
R4	0.22	605	317	137.8	43.5	0.0260
NR4	0.22	610	176	149.3	84.8	0.0138
P1	0.27	505	416	124.1	29.8	0.0076
P2	0.23	580	905	654.5	72.3	0.0243
P3	0.26	532	580	675.5	116.4	0.0195
P4	0.22	603	190	160.8	84.6	0.0147
S1	0.27	506	510	127.3	24.9	0.0159
S2	0.23	575	383	173.1	45.2	0.0065
S3	0.26	536	382	173.6	45.4	0.0084
S4	0.23	610	343	219.8	64.0	0.0033
NS4	0.22	612	262	35.3	13.5	0.0047

Table 11. Air-Void Parameters and Durability Factors of Hardened Concrete

Mixture Code	Water-to-Cementing Materials Ratio	Cementing Content, kg/m^3	Microscopical Determination of Air-Void Content in Hardened Concrete				Durability Factors
			Air Content * Fresh Concrete %	Air Content Hard Concrete %	Specific Surface (mm^2/mm^3)	Spacing Factor (mm)	300 cy.
R1	0.27	508	3.8	4.6	18.3	0.244	101
R2	0.24	581	3.8	4.9	17.7	0.238	100
R3	0.26	531	5.4	5.1	26.7	0.159	100
R4	0.22	605	4.7	6.7	20.3	0.153	99
NR4	0.22	610	2.0	3.5	8.1	0.725	99
P1	0.27	505	3.7	6.4	10.6	0.307	100
P2	0.23	580	3.9	5.2	19.0	0.236	101
P3	0.26	532	4.3	5.4	12.9	0.321	100
P4	0.22	603	4.6	7.0	25.0	0.131	100
S1	0.27	506	4.0	5.3	19.3	0.200	101
S2	0.23	575	3.8	5.0	14.3	0.323	102
S3	0.26	536	3.3	3.7	22.3	0.223	99
S4	0.23	610	4.2	4.9	17.4	0.279	99
NS4	0.22	612	2.3	4.2	8.9	0.600	100

Table 12. Drying Shrinkage, Water Permeability and Creep of Concrete

Mixture Code	Water-to-Cementing Materials Ratio	Cementing Content, kg/m^3	% Drying Shrinkage								Water Permeability	Creep of Concrete (Micro Strains)
			4 day	7 day	14 day	28 day	8 weeks	16 weeks	32 weeks	64 weeks		
R1	0.27	508	.013	.022	.031	.036	.045	.048	.058	.056	10^{-13}	
R2	0.24	581	.004	.010	.020	.028	.035	.039	.047	.047	-	
R3	0.26	531	.007	.013	.022	.028	.035	.043	.056	.051	-	
R4	0.22	605	.010	.013	.020	.027	.038	.042	.054	.046	10^{-13}	600
NR4	0.22	610	.006	.010	.019	.023	.031	.036	.048	.043	-	
P1	0.27	505	.013	.019	.025	.029	.040	.046	.059	.056	-	
P2	0.23	580	.011	.016	.026	.034	.039	.049	.059	.054	-	
P3	0.26	532	.010	.012	.018	.027	.032	.043	.054	.048	-	
P4	0.22	603	.011	.017	.021	.034	.037	.046	.057	.055	-	
S1	0.27	506	.004	.013	.027	.037	.042	.048	.060	.061	-	
S2	0.23	575	.009	.015	.023	.030	.035	.046	.056	.053	-	
S3	0.26	536	.012	.016	.021	.031	.036	.043	.056	.051	-	
S4	0.23	610	.011	.014	.020	.022	.034	.040	.051	.051	10^{-13}	1000
NS4	0.22	612	.011	.015	.024	.025	.034	.042	.051	.051	-	

DEVELOPMENT OF AIR-ENTRAINED, HIGH-STRENGTH CONCRETE: LIGHTWEIGHT CONCRETE

By

C. Bédard and K. Cail

of

CANADA CEMENT LAFARGE LIMITED

Work on this project was conducted under the auspices of the Canada Center for Mineral and Energy Technology, CANMET, Energy, Mines and Resources, Canada.

D.S.S. File No. : 23SQ.23440-4-9171

D.S.S. Contract Serial No. : 0S084-00206

CANMET Scientific Authority: Mr. G.G. Carette

AUGUST, 1987

DEVELOPMENT OF AIR-ENTRAINED, HIGH-STRENGTH CONCRETE: LIGHTWEIGHT CONCRETE

by

C. Bédard and K. Cail*

ABSTRACT

Phase I of this study showed that air-entrained, high-strength concrete with compressive strength > 80 MPa at 91 days can be produced using materials from the Atlantic provinces.

This paper investigates the production of high-strength (> 50 MPa) lightweight concrete batched in a commercial ready-mixed concrete plant. Air-entraining admixture, superplasticizer and silica fume were used. The lightweight aggregate is available from a local source.

From the test results, it is concluded that lightweight concretes with compressive strengths approaching 70 MPa at 91 days and densities of the order of 2000 kg/m^3 can be produced commercially. This type of concrete has a flexural strength of approximately 7 MPa, is air-entrained, and has satisfactory resistance to repeated cycles of freezing and thawing.

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FABRICATION DE BETON A AIR OCCLUS, A HAUTE RESISTANCE: BETON LEGER

par

C. Bédard and K. Cail *

RESUME

La première phase de l'étude a démontré qu'il était possible de fabriquer du béton à air occlus, à haute résistance, ayant une résistance à la compression supérieure à > 80 MPa, à 91 jours, en utilisant des matériaux des provinces canadiennes de l'Atlantique.

La présente étude examine la fabrication de béton léger à résistance élevée (>50 MPa) tel que dosé dans une installation commerciale de béton prêt à l'emploi. On a utilisé des adjuvants entraîneurs d'air, des superplastifiants et de la fumée de silice. Les granulats légers provenaient d'une source locale.

Les résultats des essais ont permis de conclure qu'il est possible de produire, à l'échelle commerciale, des bétons légers ayant des résistances à la compression voisines de 70 MPa, à 91 jours et des densités de l'ordre de 2000 kg/m^3. Ce béton qui possède une résistance à la flexion d'environ 7 MPa, est du type à air occlus et a une résistance satisfaisante aux alternances de gel et dégel.

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INTRODUCTION

In recent years, CANMET has become increasingly involved in research of concrete for offshore structures. In addition to the in-house studies, a number of research projects are being performed by industry under contracting-out policy of the Department. Recause of the need for high-performance concrete for offshore structures in the very severe environment of Eastern Canada, one of the research projects deals with the development of high-strength concretes using local cement and aggregates, together with chemical and mineral admixtures.

Previous investigations dealing with lightweight high-strength concrete having a 28 day compressive strength 60 MPa have been completed, and some of the results have been published ([1]). This paper reports the results of the second phase of an investigation dealing with the development of high-strength concrete (> 70 MPa) using materials from the Canadian Atlantic provinces. This phase of the investigation involved the feasibility of producing a high-strength (> 50 MPa) lightweight concrete at a commercial ready-mixed plant in St. John, New Brunswick. As well as high-strength, the concretes so developed must be air-entrained, frost resistant, and have a density of ≤ 2000 kg/m^3.

This investigation is part of CANMET's ongoing research project, "Concrete for Offshore Structures". The first phase of the investigation involved the development of high-strength (> 70 MPa) concrete in the laboratory. The mixtures incorporated fibers as well as chemical and mineral admixtures.

SCOPE OF INVESTIGATION

Unlike Phase I, all of the work in the second phase was carried out in the field at a commercial ready-mixed concrete plant. The test program consisted of a large-scale production of high-strength, lightweight concrete. The cement, fine aggregate and lightweight coarse aggregates were obtained from the Atlantic provinces. The silica fume and chemical admixtures were obtained from other parts of the country. Both mixtures incorporated a superplasticizer to maintain a minimum water-to-cementing materials ratio for a given cement content. The objective was to ensure that high-strength, lightweight concrete could be made in a producing ready-mixed plant using available materials.

MATERIALS USED

CEMENT

A.S.T.M. Type I (CSA Type 10) Portland cement manufactured in Nova Scotia was used. Chemical analysis and physical properties are given in Table 1.

CONDENSED SILICA FUME

A condensed silica fume commercially available in Quebec was used. The chemical analysis and physical properties are shown in Table 1.

AGGREGATE

A manufactured lightweight coarse aggregate of 14-mm maximum size was used. The material is produced in Minto, N.B. The relative density is 1.58 and the absorption is 13.5%.

A normal weight natural sand with a relative density of 2.61 and absorption of 1.4% was used as the fine aggregate. The sand fineness modulus was 2.69.

AIR-ENTRAINING ADMIXTURE

The air-entraining admixture used in the concrete mixtures was a sulphonated hydrocarbon type.

HIGH-RANGE WATER REDUCER (SUPERPLASTICIZER)

A sulphonated naphtalene formaldehyde condensate type superplasticizer was used in the concrete mixtures. It was a 42% aqueous solution with a density of 1.20.

CONCRETE MIXTURES

A total of 2 concrete mixtures incorporating condensed silica fume were produced in this investigation. Production of the mixtures was done at the ready-mixed concrete operations of Permanent Concrete in St. John, New Brunswick on May 13, 1986.

Mixture #1 had a Type I Portland cement content of 400 kg/m^3 and mixture #2 had 500 kg/m^3. Both mixtures incorporated condensed silica fume as an addition to the cementitious material at the rate of 30 kg/m^3. The loss of workability due to the use of silica fume was compensated for by the use of a superplasticizer. Details of the mixtures are given in Table 2.

Both of the concrete mixtures were prepared in 1.5 m^3 volume batches. Initial mixing took place in a 3 m^3 premixer for approximately 1 minute. The concrete was then discharged into a 6 m^3 drum mixer (truck mounted) for final mixing and delivery to the test site.

All materials except the silica fume and superplasticizer were weighed and batched through the regular system of the ready-mixed plant. The condensed silica fume had to be placed in the weigh hopper on top of the cement using 5 gallon pails and the superplasticizer was added manually to the mix water prior to batching.

The coarse lightweight aggregate was subjected to a water spray for 48 hours to bring it to an SSD condition. It was not possible to achieve complete SSD, therefore, additional mix water was added to compensate for a deficiency of 2.5% moisture.

The concrete mix proportions and the properties of the fresh concrete, that is slump, air content (pressure and volume method) and density were determined and are given in Table 2.

TEST SPECIMENS

A number of specimens were cast to test for compressive strength, flexural strength, modulus of elasticity, creep, shrinkage, freeze-thaw and surface scaling for each mixture.

An additional 3 large prisms were cast for each mixture for freeze-thaw and durability testing at the natural exposure site at Treat Island, Maine.

Test specimens were cast in two layers and compacted by means of rodding or vibrating table. A pencil vibrator was used for the large prisms. After casting, the moulded specimens were covered with plastic and left for 24 hours. They were then transported by truck to the standard moist curing room until required for testing.

The large prisms were moist cured, for approximately 2 months prior to being placed on the exposure site at Treat Island.

The test schedule is shown in Table 3. The test cylinders for compressive strength and for modulus of elasticity were capped with a high-strength sulphur capping compound in accordance with ASTM C-39 for compressive strength at various ages up to 365 days and ASTM C-469 for modulus of elasticity at 28 and 365 days. Test prisms were used to determine the flexural strength at 28 and 365 days.

The test prisms for drying shrinkage were subjected to air drying after an initial moist curing period of 28 days. Shrinkage strains were monitored at 23 ± 1.7°C and 50 ± 4% of relative humidity.

Freezing and thawing tests were performed on two prisms per mixture using Procedure A of ASTM C-666, with the specimens being subjected to a total of 300 repeated cycles of freezing and thawing in water.

The creep strains were determined according to ASTM C-512 for a period of 365 days. A constant applied stress of 40% of the compressive strength of the concrete at the age of loading was applied.

As well, three 300 x 300 x 900-mm concrete prisms were cast from each mixture for long-term durability testing at the Treat Island exposure site. The results will be monitored under a separate CANMET project investigating long-term durability aspects.

TEST RESULTS

The compressive strength test results for the 100 x 200-mm and the 150 x 300-mm test cylinders along with the flexural strength test results and modulus of elasticity data for the two mixtures are given in Table 4.

Values for the drying shrinkage, freeze-thaw results and creep are presented in Table 5.

DISCUSSION

Both the 400 and 500 mixtures were stiff and "gluey" to work with but under vibration became quite workable. The mixing action of the premixer and the drum mixer gave a homogeneous mixture free of segregation or inadequate blending.

Some problem was encountered with the amount of time required to mould the large number of test specimens. Because of the relativlely high ambient temperature (25°C) and low water/cement ratio, the mixtures showed early stiffening characteristics. Future work of this nature should incorporate a compatible retarder to extend the set time.

No difficulty was experienced in entraining air in the two concrete mixtures. A 2% difference was observed between the pressure method and the volume method of measuring air. Using the volume method, mixture #1 (400) gave 7.0% air and mixture #2 (500) 4.0% air. The corresponding densities were 1948 kg/m^3 and 2025 kg/m^3, respectively.

COMPRESSIVE STRENGTH

The average 91 day compressive strength for mixture #1 was 52.0 MPa and mixture #2 was 68.1 MPa. A small gain was experienced up to 1 year, with the average compressive strength being 55.7 MPa and 69.5 MPa, respectively (Table 4).

FLEXURAL STRENGTH

The 28 day and 1 year flexural strength results for mixture #1 were 5.9 MPa and 7.1 MPa. The corresponding results for mixture #2 were 6.7 MPa and 7.2 MPa, respectively (Table 4).

MODULUS OF ELASTICITY

The 28 day and 1 year Young's modulus of elasticity values for mixture #1 were 20.3 GPa and 23.0 GPa, respectively. The corresponding 28 day and 1 year values for mixture #2 were 24.7 GPa and 26.3 GPa.

DRYING SHRINKAGE

The drying shrinkage of the test prisms was determined over a period of 64 weeks, with the first readings being taken at 7 days after an initial moist curing period of 28 days. All specimens were air dried at 50% relative humidity and at 23°C ± 1.76°C. These test values show that the drying shrinkage is little affected by the use of lightweight aggregate.

FREEZE-THAW DURABILITY

The performance of the concrete from both mixtures under freezing and thawing was excellent. This is no doubt due to air-entrainment and the low water/cement ratio of the concretes.

The durability factor after 300 cycles for mixture #1 was 93.3 and mixture #2 was 97.6. Surface scaling in the presence of deicer salts (ASTM C672) also gave very good results at 50 cycles of freezing and thawing (Table 6).

CREEP

The load-induced time dependent creep for both mixtures was 970 microstrains at one year. The difference in compressive strength had an unmeasurable difference in the creep results between the two mixtures.

CONCLUSIONS

1. The results of this investigation show that high-strength, air-entrained, lightweight concrete can be produced satisfactorily at a commercial ready-mixed plant. The density of such fresh concrete incorporating 500 kg of cement and 30 kg of silica fume/m^3 of concrete was 2025 kg/m^3. Densities less than 1900 kg/m^3 could be achieved by using lightweight sand (partial blending).

2. A compressive strength greater than 65 MPa was obtained under field conditions.

3. The freezing-thawing resistance of the concretes was excellent, with durability factors of greater than 90.

ACKNOWLEDGEMENTS

The concrete mixtures were prepared at the operations of Permanent Concrete in St. John, New Brunswick and the laboratory investigations were performed at the Research and Technical Center of Canada Cement Lafarge Ltd. in Montreal. The work was carried out under D.S.S. Contract No. 23Q.23440-4-9171. The CANMET Scientific Authority for the project was Mr. G.G. Carette and the principal researcher at Canada Cement Lafarge was Kevin Cail. The investigation was performed in accordance with the Work Statement prepared by the Scientific Authority.

REFERENCES

1. Seabrook, P.T. and Wilson, H.S., "High Strength, Semilightweight for Use in Offshore Structures: Utilization of Fly Ash and Silica Fume"; CANMET Division Report MSL 86-127 (OP & J) Draft; Energy, Mines and Resources Canada; 26 pp., 1986.

TABLE 1: CHEMICAL ANALYSIS AND PHYSICAL PROPERTIES OF PORTLAND CEMENT AND CONDENSED SILICA FUME

DESCRIPTION OF TEST	A.S.T.M. TYPE I	SILICA FUME
Chemical Analysis, %		
SiO_2	19.7	95.41
Al_2O_3	5.1	1.09
Fe_2O_3	2.2	0.00
CaO	63.6	0.32
MgO	1.4	0.73
Na_2O	0.23	-
K_2O	1.25	0.61
SO_3	4.19	0.24
Loss on Ignition	2.00	1.80
Total	99.7	99.20
Potential Compound Composition, %		
C_4AF	6.6	
C_3A	9.9	
C_3S	59.7	
C_2S	11.5	
$C_3S + C_2S$	71.2	
Physical Tests		
Time of Set (Vicat) Initial (min.)	123	
Final (min.)	-	
Fineness (45 um), %	89.0	
Blaine Surface Area, m^2/kg	358	
Fineness		19,000 m^2/kg
Water Requirement		139
Pozzolanic Activity Index with:		
Portland Cement @ 28 d,		119.1
% Lime, (MPa)		12.5
Compressive Strength @:		
3-d (MPa)	29.7	
7-d (MPa)	34.6	
28-d (MPa)	38.9	

TABLE 2: MIXTURE PROPORTIONS AND PROPERTIES OF FRESH CONCRETE

MIXTURE PROPORTIONS FOR $1m^3$ OF FRESH CONCRETE									PROPORTIONS OF FRESH CONCRETE			
MIXTURE CODE	WATER-TO-CEMENT RATIO	WATER-TO-CEMENTING MATERIALS RATIO	CEMENT kg	SILICA FUME kg	FINE AGGREGATE kg	LIGHTWEIGHT COARSE AGGREGATE kg	WATER kg	SUPER-PLASTICIZER % BY WEIGHT OF CEMENT	SLUMP mm	AIR CONTENT PRESSURE METHOD %	AIR CONTENT VOLUME METHOD %	DENSITY kg/m^3
Mixture #1	0.36	0.33	400	30	660	635	145	0.75	120	9.3	7.0	1948
Mixture #2	0.28	0.26	500	30	700	550	140	0.96	80	6.0	4.0	2025

TABLE 3: TESTING SCHEDULE FOR HARDENED CONCRETE

TEST	AGE	NO. OF SPECIMENS TESTED PER MIX		
		#	100x200	150x300
1) Compressive Strength (ASTM C-39) of 100 x 200-mm cylinders and 150 x 300-mm cylinders	3-d 7-d 28-d 91-d 1-y		3 3 3 3	2 2 2 2 2
2) Flexural Strength (ASTM C-78) of 75 x 75 x 350-mm prisms	28-d 1-y	2 2		
3) Modulus of Elasticity (ASTM C-469) of 150 x 300-mm cylinders	28-d 1-y	2 2		
4) Length Change of Hardened Concrete (Shrinkage) in Air Storage (ASTM C-157), as measured on 75 x 75 x 300-mm prisms		2		
5) Resistance of Concrete to Rapid Freezing and Thawing (ASTM C-666, Proc. A), as measured on 75 x 75 x 300-mm prisms		2		
6) Creep of Concrete in Compressioners (ASTM C-512), as measured on 150 x 300-mm cylinders		5		
7) Scaling Resistance of Concrete Surfaces Exposed to De-Icing Chemicals (ASTM C-672)		1		

TABLE 4: PROPERTIES OF HARDENED CONCRETE
STRENGTH PROPERTIES AND YOUNG'S MODULUS OF CONCRETE

			COMPRESSIVE STRENGTH					FLEXURAL STRENGTH		MODULUS OF ELASTICITY	
MIXTURE CODE	WATER-TO-CEMENT RATIO	CEMENTING CONTENT kg/m^3	3 DAY (MPa)	7 DAY (MPa)	28 DAY (MPa)	91 DAY (MPa)	1 YEAR (MPa)	28 DAY (MPa)	1 YEAR (MPa)	28 DAY (GPa)	1 YEAR (GPa)
MIXTURE #1	0.33	430						5.9	7.1	20.3	23.0
100x200mm			33.5	41.9	51.3	56.3	-				
150x300mm			29.9	38.8	48.2	52.0	55.7				
MIXTURE #2	0.26	530						6.7	7.2	24.7	26.3
100x200mm			51.0	56.3	68.4	69.6	-				
150x300mm			50.1	54.7	59.5	68.1	69.5				

TABLE 5: PROPERTIES OF HARDENED CONCRETE
DRYING SHRINKAGE, DURABILITY AND SURFACE SCALING AND CREEP OF CONCRETE

			% DRYING SHRINKAGE									
MIXTURE CODE	WATER-TO-CEMENTING MATERIALS RATIO	CEMENTING CONTENT kg/m^3	7 DAY	14 DAY	28 DAY	84 DAY	140 DAY	252 DAY	365 DAY	DURABILITY FACTOR 300 CYCLES	SURFACE SCALING VISUAL RATING	CREEP OF CONCRETE (MICRO-STRAINS)
MIXTURE #1	0.33	430	.0010	.0020	.0035	.0165	.0365	.0560	.0710	93.3	0.5	970
MIXTURE #2	0.26	530	.0002	.0003	.0035	.0100	.0235	.0475	.0634	97.6	0.0	970